RESEARCH MEMORANDUM

DRAG MEASUREMENTS AT TRANSONIC SPEEDS OF NACA 65-009 AIRFOILS MOUNTED ON A FREELY FALLING BODY TO DETERMINE THE EFFECTS OF SWEEPBACK AND ASPECT RATIO

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DRAG MEASUREMENTS AT TRANSONIC SPEEDS OF NACA 65-009 AIRFOILS MOUNTED ON A FREELY FALLING BODY TO DETERMINE THE EFFECTS OF SWEEPBACK AND ASPECT RATIO

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SUMMARY

Drag measurements at transonic speeds on rectangular airfoils and on airfoils swept back 45° are reported. These airfoils, which were mounted on cylindrical test bodies, are part of a series being tested in free drops from high altitude to determine the effect of variation of basic airfoil parameters on airfoil drag characteristics at transonic speeds. These rectangular and swept-back airfoils had the same span, airfoil section (NACA 65-009), and chord perpendicular to the leading edge. The tests were made to compare the drag of rectangular and swept-back airfoils at a higher aspect ratio than had been used in a similar comparison reported previously.

The results showed that the drag of the swept-back airfoil was less than 0.15 that of the rectangular airfoil at a Mach number of 1.00 and less than 0.30 that of the rectangular airfoil at a Mach number of 1.17.

A comparison of these swept-back airfoils with similar airfoils of lower aspect ratio previously tested by the same method indicated that in the investigated speed range reduction in aspect ratio results in increased drag. In the highest part of the investigated speed range, however, the drag coefficient of the high-aspect-ratio swept-back airfoils showed a tendency to approach that of the lower-aspect-ratio swept-back airfoils. A similar comparison for the rectangular airfoils showed

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that delay in the drag rise and a reduction in drag at supercritical speeds can be realized through reduction in aspect ratio. These results confirm those reported in NACA ACR No. L5J16.

INTRODUCTION

A serious limitation on practical flight in the transonic-speed range results from the large abrupt increases in drag of conventional airplane configurations as sonic speed is approached. Because of the importance of this problem, a series of tests is being conducted at the Langley Memorial Aeronautical Laboratory of the NACA to determine aerodynamic shapes and configurations that have a minimum of drag at transonic speeds. In these tests, data are telemetered from special test configurations during free fall from high altitude. Previous tests in which this method was employed were reported in references 1 and 2. The object of the present tests was to compare the drag of rectangular and swept-back airfoils at a higher aspect ratio than had been used in a similar comparison reported in reference 2.

For the tests reported herein drag measurements were made on rectangular airfoils and on airfoils having 45° sweepback. These airfoils incorporated NACA 65-009 sections of equal chord perpendicular to the leading edge and differed from the airfoils of reference 2 only by an increase in span. The subscript 1 has been deleted from the designation of NACA 6-series airfoils with thickness ratios less than 0.12 of the chord. The airfoil designated 65-009 in the present paper, therefore, is the airfoil section designated 65_1-009 in reference 2.

The results of the tests on these airfoils are presented as curves showing the variation of drag coefficient with Mach number in the transonic-speed range. Comparable curves are also presented for the airfoils of reference 2.

APPARATUS AND METHOD

Test configurations.- The general arrangement of the two test configurations is shown in figure 1, and details and dimensions are shown in figure 2. The airfoils were mounted on bodies identical with those of reference 2. These bodies were cylinders of $10\frac{3}{4}$-inch diameter and were fitted with a pointed nose and a small tail fairing. The airfoils were located near the rear of the cylindrical part of the body and entered the body through rectangular slots $9\frac{1}{2}$ inches long and 1 inch wide. The airfoils were staggered so that front and rear airfoil sets could be mounted on separate spring balances. This arrangement has the additional advantage of reducing the interference effects of the rear airfoil on the front airfoil.

Both the rectangular airfoils and the airfoils having 45° sweepback had NACA 65-009 sections of 8-inch chord perpendicular to the leading edge and equal spans of 25 inches outboard of the body as compared with 15 inches for the otherwise identical airfoils of reference 2.

The nominal aspect ratio b^2/S for the present swept-back airfoils was 5.4 as compared with 3.6 for the swept-back airfoils previously tested, where b is the over-all span of each airfoil set and S is the plan area of each airfoil set including that within the body. Corresponding nominal aspect ratios for the rectangular airfoils were 7.6 and 5.1, respectively.

Measurements.- Measurement of the desired quantities was accomplished as in the previous tests (reference 2) through use of the NACA radio-telemetering system and radar and phototheodolite equipment. The following quantities were recorded at two separate ground stations by the telemetering system:

(1) The force exerted on the body by each set of airfoils as measured by a spring balance

(2) The total retardation of the body and airfoils as measured by a sensitive accelerometer alined with the longitudinal axis of the body

(3) The local static pressure at a station on the body $1\frac{1}{2}$ chords ahead of the front airfoil as measured by four orifices connected to an aneroid pressure cell (see fig. 2).

A time history of the position of the body during its fall was recorded with respect to ground axes by the radar and phototheodolite equipment, and a survey of atmospheric conditions applying to each test was obtained from synchronized records of atmospheric pressure, temperature, and geometric altitude taken during the descent of the airplane from which the bodies were dropped.

Reduction of data.- As in the previous tests the velocity V of the body during its fall was obtained both by differentiation of the flight path as determined from radar and phototheodolite records and by integration of the vector sums of gravitational acceleration and the directed retardation as measured by the accelerometer. The drag D of each set of airfoils was obtained from the relation

$$D = R + W_t a_e$$

where

R measured reaction between airfoil and body, pounds

W_t weight of airfoil assembly, pounds

a_e reading of accelerometer (retardation), g

The atmospheric pressure p, the temperature T, and the airfoil frontal area F were combined with the simultaneous values of velocity and airfoil drag to obtain Mach number M and the ratio D/Fp. A curve of this parameter D/Fp against Mach number affords a simple and convenient means for expressing drag in the transonic-speed range as a function of Mach number, altitude, and size.

Values of conventional drag coefficient based on frontal area C_{D_F} were obtained from the relation

$$C_{D_F} = \frac{D/Fp}{\frac{\gamma}{2} M^2}$$

where the ratio of specific heats γ was taken as 1.4. Drag coefficient C_D based on plan area was obtained by multiplying values of C_{D_F} by the ratio of frontal area to plan area. Areas used did not include those within the body.

RESULTS AND DISCUSSION

Time histories of the pertinent quantities obtained from each test are given in figures 3 and 4. A check on the over-all accuracy of the velocity and retardation measurements is provided in these figures by a comparison of the velocity obtained from flight-path data (test points and solid fairing) with the velocity obtained from acceleration data (dashed fairing). The maximum discrepancy in velocity obtained by these two independent methods may be seen to be about 10 miles per hour. If the source of this error is wholly in the measurement of retardation, the corresponding mean accelerometer error would be of the order of 0.01g, which is within the expected limit of accuracy of this instrument. The velocities used to compute the Mach number were those taken from the fairing of the flight-path data. The acceleration data, however, were used as a guide for this fairing, particularly in the fairing of the last few seconds of the data shown in figure 3, where photographs used for correcting small errors in pointing of the phototheodolite were not obtained.

Figures 3 and 4 also afford a comparison between the variations of atmospheric pressure and local static pressure $1\frac{1}{2}$ chords ahead of the front airfoil. Except in the immediate vicinity of Mach number 1.00, where abrupt changes in local static pressure are quite definitely indicated, the two pressure measurements agree within the probable limit of accuracy of the telemetering system. Because of this limitation on accuracy, further tests must be made before the validity of the smaller differences can be definitely established. The differences between the subsonic values of atmospheric and local static pressure in figure 3, however, suggest the presence of a blocking effect caused by the airfoils, although the magnitude of this error is larger than would normally be encountered at low subsonic speeds.

The results of the tests are summarized in figure 5, where curves are presented that show the variations of D/F_p and C_D with flight Mach number for the rectangular and for the swept-back airfoils. The results for the front and rear airfoils are presented separately because interference effects between body and airfoils and between airfoils may cause the small discrepancies. Because of the possibility of interference effects, data for the front airfoils should be the more reliable, particularly at supersonic speeds.

The accuracy of the values of D/F_p shown in figure 5 varies throughout the drop from about ± 0.02 at $M = 0.85$ to about ± 0.006 at $M = 1.20$. This variation is due to the increase in atmospheric pressure during the fall of the test bodies and to the fact that the airfoil drag was determined with constant accuracy (± 3 lb). Corresponding values for the accuracy of C_D are about ± 0.0035 at $M = 0.85$ and about ± 0.0005 at $M = 1.20$. The accuracy with which flight Mach number was determined was about ± 0.01, but since the velocity was determined with respect to ground reference the effect of wind has been neglected. This effect may cause the Mach number determination to be slightly more inaccurate than is indicated by the foregoing value at the lowest Mach number for which results are presented. Such error rapidly becomes negligible with increase in Mach number because the flight path of the test body quickly departs from horizontal during its fall, and, in general, wind velocities are less at the lower altitudes.

The curves of D/F_p in figure 5 show that for the rectangular airfoil the drag per square foot of frontal area increased abruptly from 0.04 of atmospheric pressure at a flight Mach number of 0.85 to 0.42 of atmospheric pressure at a Mach number of 1.00 and then increased at a slower rate to 0.61 at a Mach number of 1.17. For the swept-back airfoil the drag per square foot of frontal area increased from 0.02 of atmospheric pressure at a flight Mach number of 0.85 to 0.26 of atmospheric pressure at a Mach number of 1.25 without evidencing the abrupt drag rise characteristic of the rectangular airfoil. The drag per square foot of frontal area for the swept-back airfoil was less than 0.15 that for the rectangular airfoil at a Mach number of 1.00 and less than 0.30 that of the rectangular airfoil at a Mach number of 1.17. The measured difference in total drag of the two bodies agrees with the measured difference in airfoil drag within the limits of accuracy of the accelerometer (±0.09 in D/F_p at a Mach number of 0.85 and ±0.025 in D/F_p at a Mach number of 1.20).

Figure 6 shows the effect of aspect ratio on the drag characteristics of rectangular and swept-back airfoils. The variations of D/F_p with Mach number for the present rectangular airfoils and for the rectangular airfoils of reference 2 are given in figure 6(a). These curves show that increase of the nominal aspect ratio from 5.1 to 7.6 reduced the Mach number at which the drag rise started by about 0.02 and increased the values of D/F_p above the drag rise by about 0.03. This effect of aspect ratio verifies the results of reference 3, which indicate that a delay in the drag rise and a reduction in drag at supercritical speeds can be realized for rectangular wings through decrease in aspect ratio.

Similar variations of D/F_p with Mach number for the present swept-back airfoils and for the swept-back airfoils of reference 2 are given in figure 6(b). These curves show that increase in aspect ratio of the swept-back airfoils from 3.6 to 5.4 resulted in a decrease in D/F_p in the investigated speed range. This condition may indicate flow disturbances at the root or tip of the airfoils where the ideal three-dimensional flow conditions around a swept-back airfoil of infinite span do not exist. The drag resulting from disturbances at the root or tip would be a greater part of the total drag for the low-aspect-ratio airfoil. It may be noted from the curves in figure 6(b), however, that the values of D/F_p for the high-aspect-ratio airfoils show a tendency to approach those of the low-aspect-ratio airfoils at the highest Mach number investigated.

CONCLUDING REMARKS

Drag measurements at transonic speeds attained in free fall from high altitude have been made on rectangular airfoils and on airfoils swept back 45°. These airfoils had NACA 65-009 sections, a $60\frac{3}{4}$-inch span, and an 8-inch chord perpendicular to the leading edge. They were mounted on a $10\frac{3}{4}$-inch-diameter cylindrical body. The results of the tests showed that the drag per square foot of frontal area for the swept-back airfoil was less than 0.15 that for the rectangular airfoil at a Mach number of 1.00 and less than 0.30 that of the rectangular airfoil at a Mach number of 1.17.

A comparison of these results with the results of the previous tests on $40\frac{3}{4}$-inch-span NACA 65-009 airfoils having 8-inch chord shows that

(1) For the airfoils swept back 45° increase in aspect ratio from 3.6 to 5.4 produced an appreciable reduction in drag between Mach numbers of 0.95 and 1.2 but only a slight reduction at the highest Mach number (1.25) reached in the tests.

(2) For the rectangular airfoils an increase in aspect ratio from 5.1 to 7.6 reduced the Mach number at which the drag rise started by about 0.02 and resulted in somewhat higher drag throughout the speed range investigated.

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Langley Field, Va.

REFERENCES

1. Bailey, F. J., Jr., Mathews, Charles, W., and Thompson, Jim Rogers: Drag Measurements at Transonic Speeds on a Freely Falling Body. NACA ACR No. L5E03, 1945.

2. Mathews, Charles W., and Thompson, Jim Rogers: Comparative Drag Measurements at Transonic Speeds of Rectangular and Swept-Back NACA 65_1-009 Airfoils Mounted on a Freely Falling Body. NACA ACR No. L5G30, 1945.

3. Stack, John, and Lindsey, W. F.: Characteristics of Low-Aspect-Ratio Wings at Supercritical Mach Numbers. NACA ACR No. L5J16, 1945.

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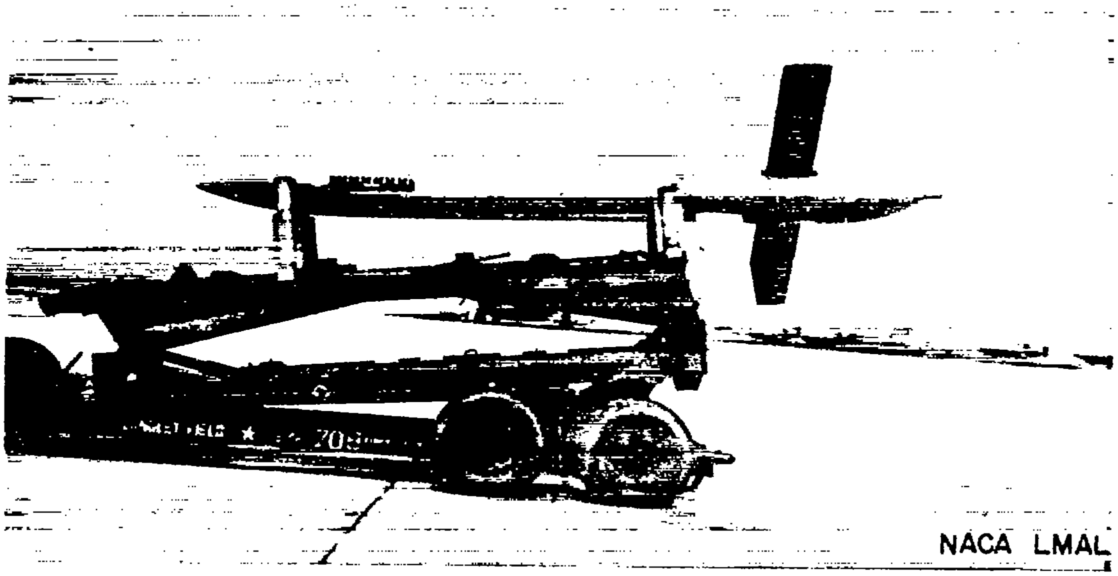
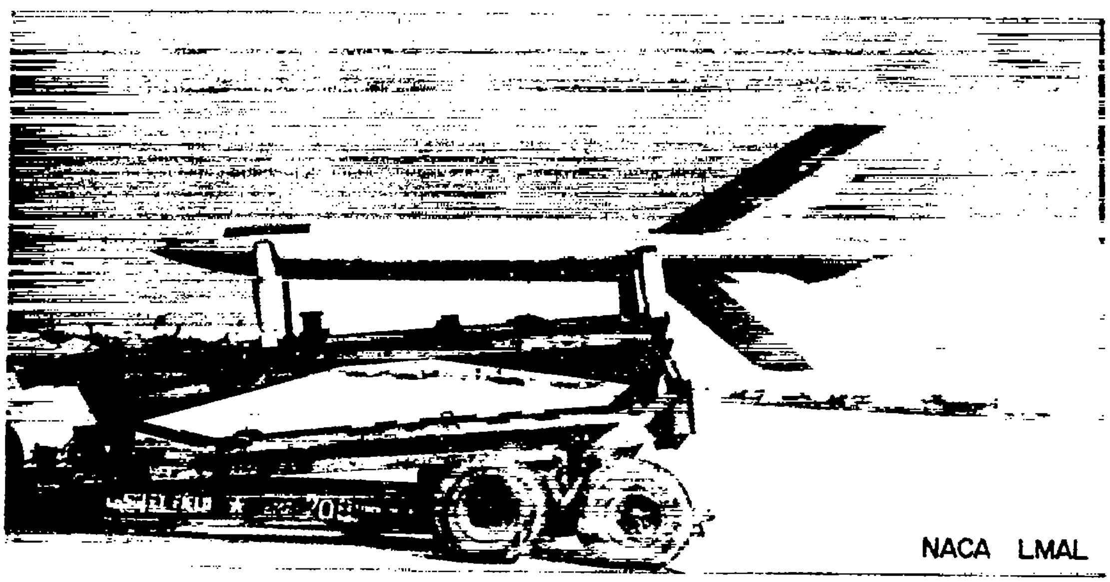


(a) Rectangular airfoil.



(b) Swept-back airfoil.

Figure 1.- General views of airfoil test bodies.

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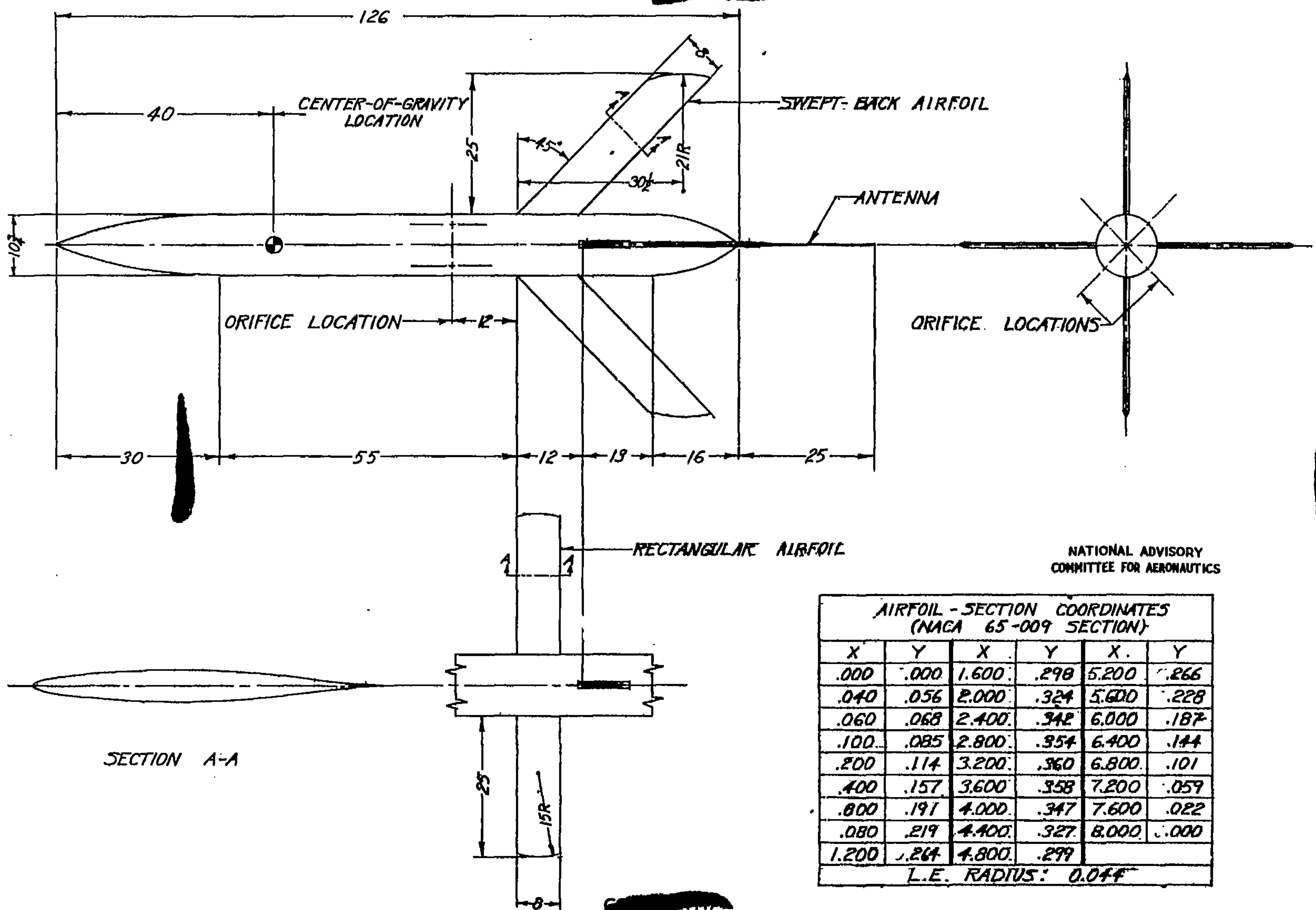

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AIRFOIL - SECTION COORDINATES (NACA 65-009 SECTION)					
X	Y	X	Y	X	Y
.000	.000	1.600	.298	5.200	.266
.040	.056	2.000	.324	5.600	.228
.060	.068	2.400	.342	6.000	.187
.100	.085	2.800	.354	6.400	.144
.200	.114	3.200	.360	6.800	.101
.400	.157	3.600	.358	7.200	.059
.800	.191	4.000	.347	7.600	.022
.080	.219	4.400	.327	8.000	.000
1.200	.264	4.800	.299		
L.E. RADIUS: 0.044					

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Figure 2.- General arrangements and dimensions of airfoil test bodies. All dimensions are in inches.

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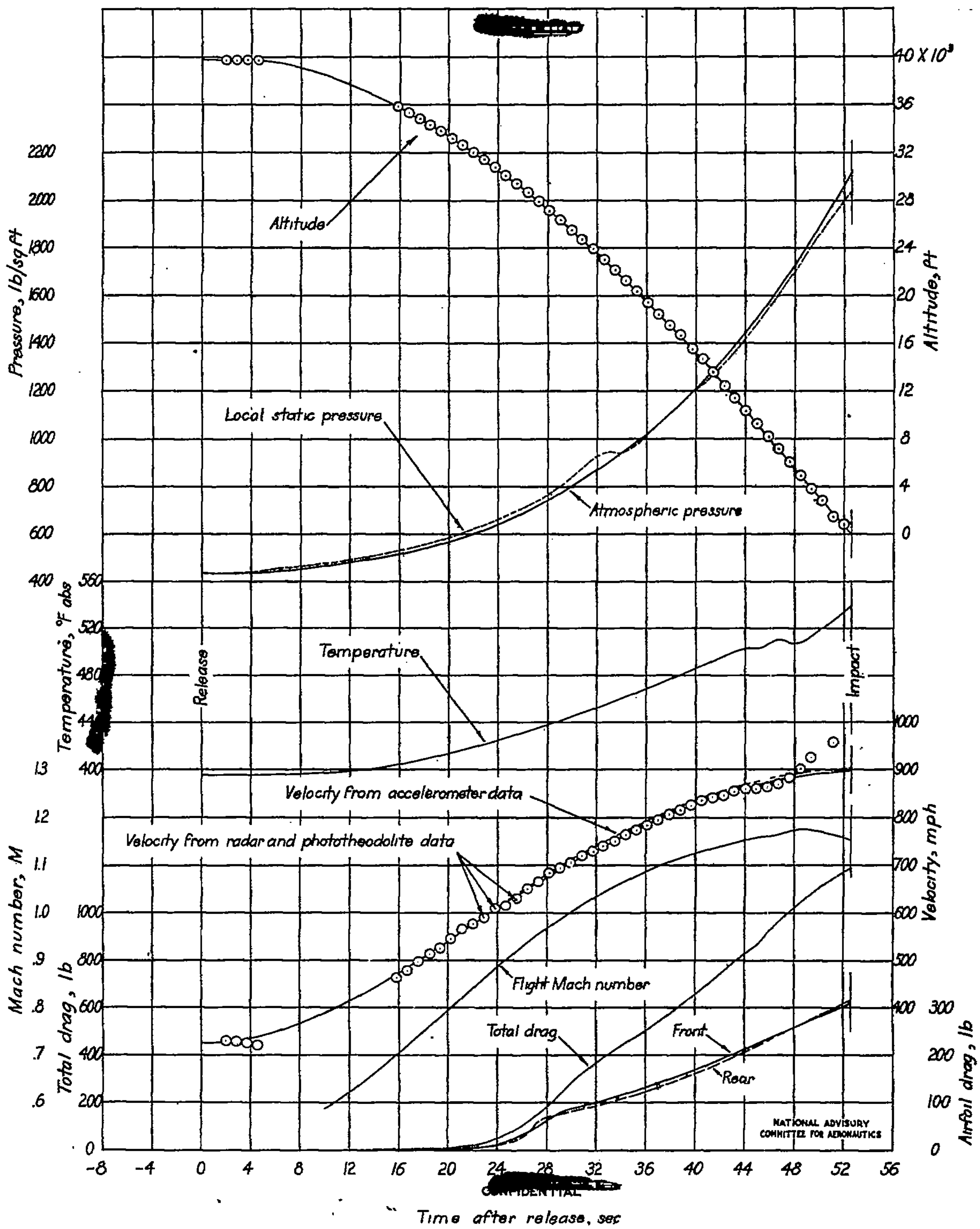

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Figure 3.- Time history of free fall of 1322-pound test body mounting rectangular airfoils. NACA 65-009 airfoil section.

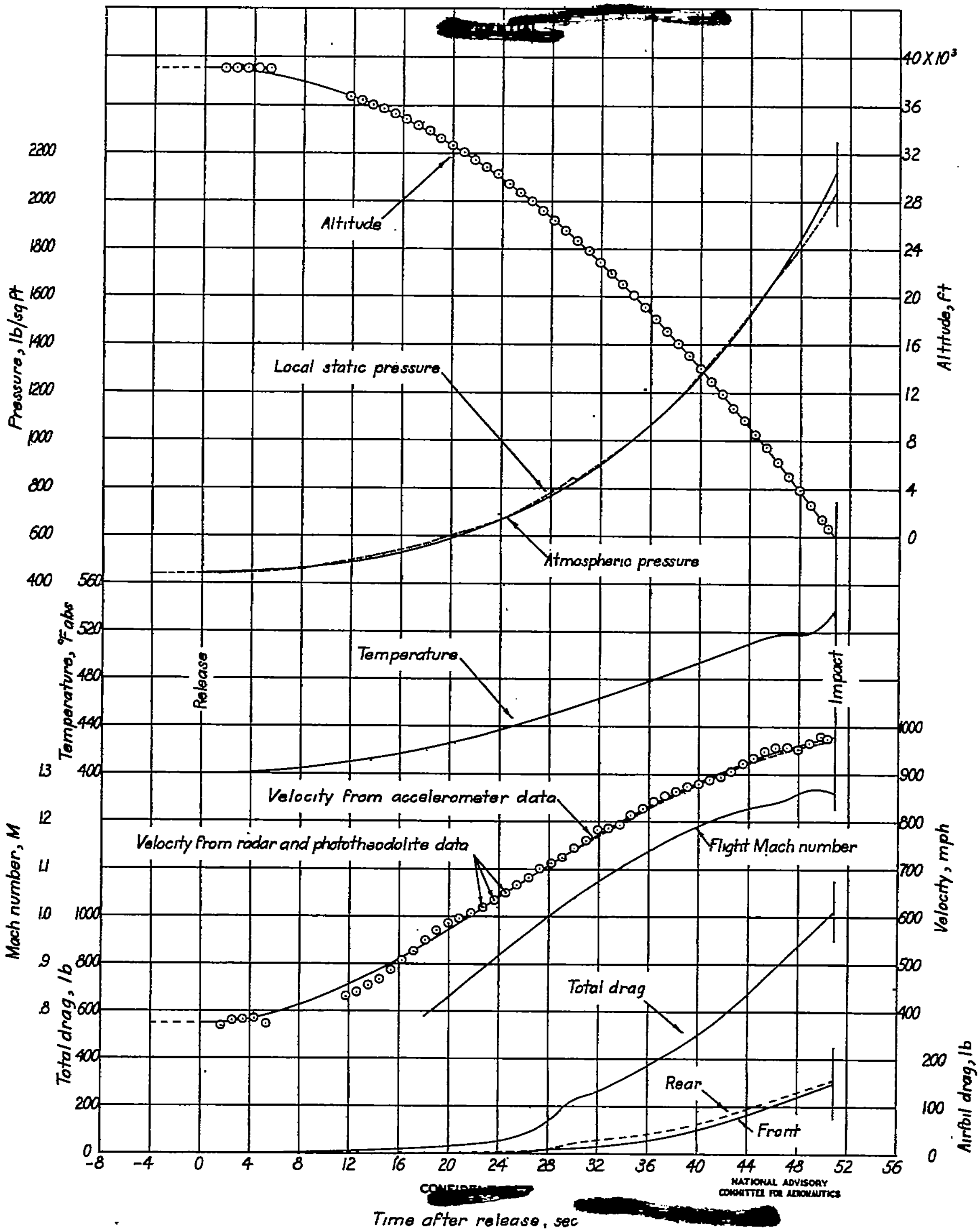

Figure 4.- Time history of free fall of 1330-pound test body mounting airfoils having 45° sweepback. NACA 65-009 airfoil section.

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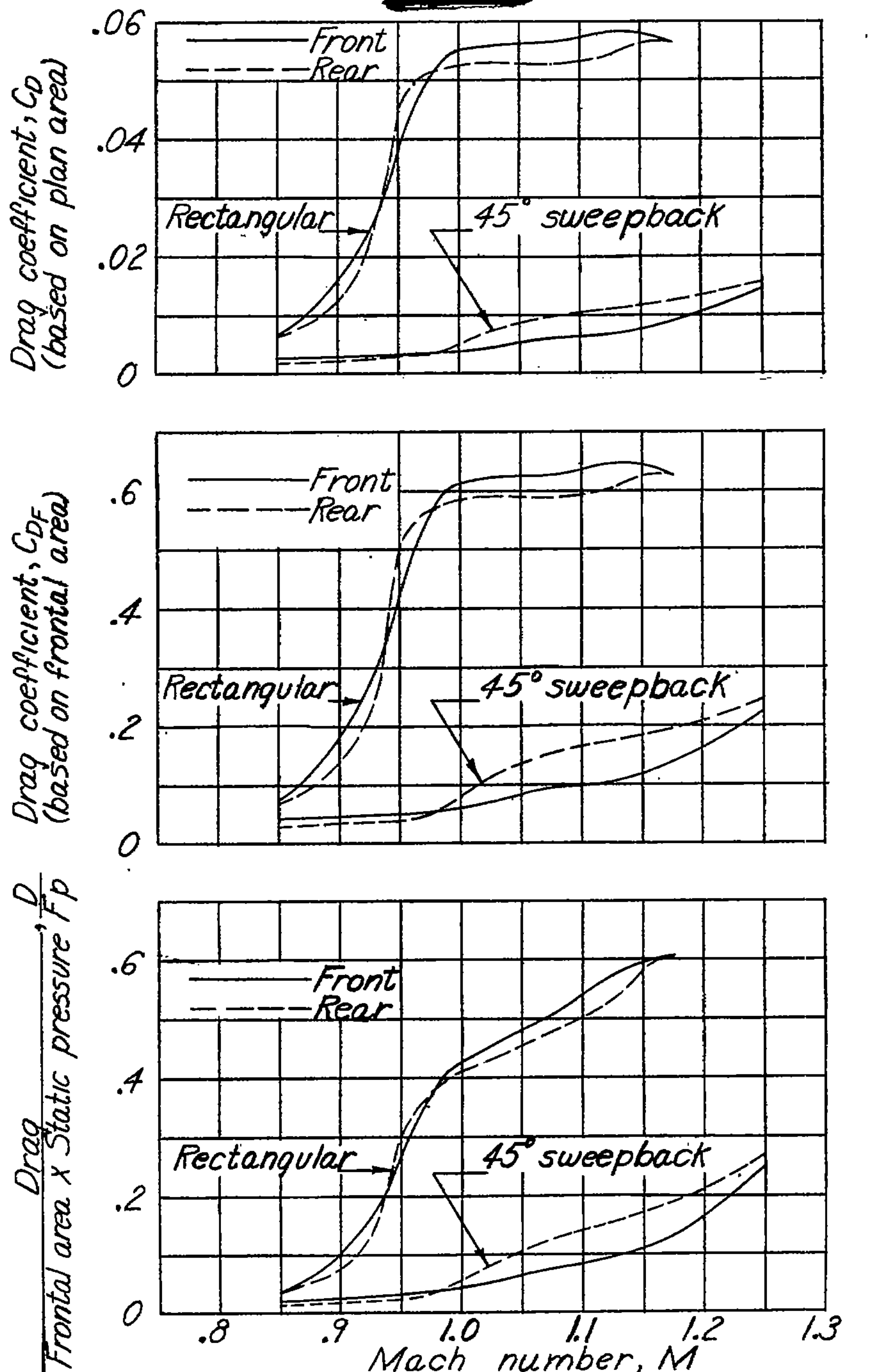

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Figure 5.- Variation of airfoil drag coefficients and D/Fp with Mach number for rectangular airfoils and airfoils having 45° sweepback.

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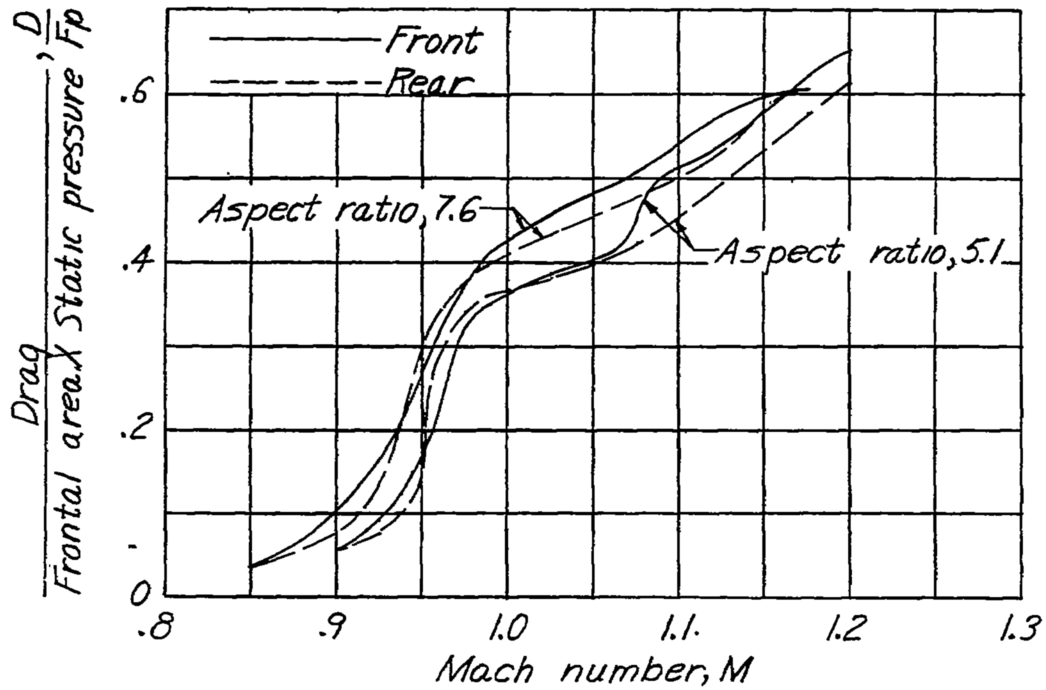
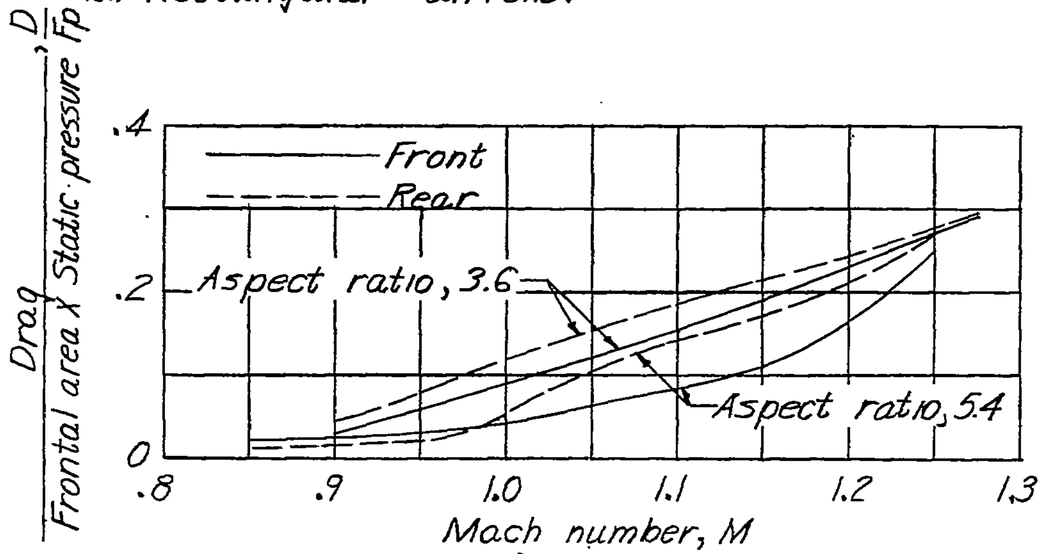


(a) Rectangular airfoils.



(b) Airfoils having 45° sweepback.

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Figure 6.- Effects of aspect ratio on variation of D/Fp with Mach number for rectangular airfoils and airfoils having 45^{0} sweepback.

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